EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

ISR-BOM/HL/rh I-1068/ISR/LEP

SPECIFICATION

OF PRECISION-PUNCHED LAMINATIONS FOR THE LEP DIPOLE MAGNETS

The European Organization for Nuclear Research (CERN) is constructing a Large Electron Positron Storage Ring, called LEP. For the cores of the dipole magnets of this ring, a total of about 3 600 000 laminations have to be precision punched out of decarburized soft magnetic steel sheets.

The present specification concerns the technical requirements for the steel sheets, the punching and the supply of pre-stacked batches of laminations to the core factories.

Geneva, Switzerland
19 March 1982

Production schedule

The adjudication will be based on the dates indicated in the Tender Form.

The exact delivery dates will be fixed in the contract.

2. STEEL SHEETS

The steel sheets for the cores of the LEP dipole magnets may only be supplied by a qualified steel maker according to Appendix 2 of the present specification.

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The acceptance tests for the magnetic properties of the entire steel production will be handled by CERN and the steel maker. The punching firm will be notified by CERN of the result of these tests for each batch of steel sheets.

2.2 Geometrical and mechanical properties of the steel sheets

It can be expected that the steel sheets will have an elastic limit of about 100 to 150 N mm^{-2}, a tensile strength of about 200 to 250 N mm^{-2} and a hardness of about 80 HB. The chemical composition will be characterized by a very low content of impurities, i.e. about 0.003 % C, 0.2 % Mn, 0.02 % S, 0.01 % P, 0.05 % Cu, 0.02 % Cr, 0.02 % Ni, 0.02 % Sn, 0.02 % As.

Some basic requirements for geometrical and mechanical properties of the steel sheets have been specified in Section 2 of the "Specification of the steel sheets for the LEP dipole magnets" (Appendix 1)

The final complete and precise geometrical and mechanical specification of the steel sheets will be the entire responsibility of the punching firm and the steel maker. However, CERN's agreement with this specification

will have to be obtained. This specification and the CERN magnetic specification must be an integral part of the contract between the two firms.

It will be the responsibility of the punching firm to define, in agreement with the steel maker, the precise method of inspection and to systematically perform adequate geometrical and mechanical acceptance tests of the steel sheets before delivery. CERN must be informed of the inspection methods used and have free access to the results.

2.3 Form of delivery

In Section 3 of the "Specification of the steel sheets for the LEP dipole magnets" (Appendix 1), CERN has suggested sheet dimensions of 500 mm width and 520 or 1020 mm length for punching one or two laminations per sheet. These seem to be reasonable sizes for cutting and manipulating the soft steel sheets at the steel maker's premises and at the punching works. It is, however, understood that the final dimensions and tolerances will be defined by the punching firm in agreement with the steel maker. The use of sheets with approximate dimensions of 500 mm x 520 mm for punching one lamination per sheet may be favoured for automated punching.

3. PUNCHING OF THE LAMINATIONS

3.1 Description of the laminations

The following description refers to the reference numbers placed in circles in Fig. 3.

1 The pole profiles with shims at both ends determine the field distribution in the gap and must be punched very precisely (Fig. 4).

2) These reference faces serve to position the laminations during stacking and moulding; they must be precision-punched with respect to the pole profiles.

3) Through the four 40 mm Ø holes, prestress wires will pass to keep the finished cores permanently under defined compressive forces.

4 These slots will serve for fixing other machine components on the installed magnets in the LEP tunnel.

5) Aluminium excitation bars will be placed in this window.

6) The reference notches on top and at the bottom of the poles' axis of the laminations will be used for the geometrical alignment of the finished magnets in the LEP tunnel. They must be precision-stamped with respect to the pole profiles.

3.2 Indentations for spacing the laminations

During the fabrication of the steel-concrete cores at the core factories, regular and accurate spacing of the punched steel laminations must be ensured. For this purpose, indentations will have to be precision-stamped into both sides of the laminations (reference number 7 in Fig. 3). These indentations are arranged in pairs. The distance between the two indentations of each pair has been chosen such that the required compressive force for the compensation of height tolerances of these stamped indentations remains within a range of about 200 to 1500 N when the length of the magnet core is being adjusted to its nominal value of 5760 mm.

For a limited number of laminations (6800 pieces), the indentations will have to be stamped only into one side of the sheets. During core assembly, one of these laminations will always be placed at each end of the core.

3.3 Punching tool

The precise procedure for punching, the punching tool and its materials will be the entire responsibility of the punching firm. Experience with similar magnets and with prototype magnets for LEP has shown that punching these very soft steel sheets requires very small clearances between die and punch and a good guidance of the moving parts in order to obtain the narrow tolerances. This experience also indicates that two successive punching steps are required to cope with the release of internal stresses of the steel sheets during punching. Based on this experience, CERN requires that the laminations be punched in two steps. During the first step, a surplus of material of a few millimetres is left in the places where tight tolerances are required (hatched areas in Fig. 3), which is removed during the second operation. The indentations should be stamped in the first step.

APPENDIX 1
to CERN Specification I-1068/ISR/LEP
"Precision-punched laminations for the LEP dipole magnets"

SPECIFICATION OF THE STEEL SHEETS FOR THE LEP DIPOLE MAGNETS

This appendix concerns the technical requirements for the supply of the steel sheets to the punching works.

The magnetic characteristics of the steel and the acceptance procedures are described in detail. As for the geometrical and mechanical characteristics of the sheets, only some basic requirements are indicated. They will have to be complemented by the detailed specification of the punching works.

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MAGNETIC PROPERTIES OF THE STEEL SHEETS

1.1 Type of steel

The LEP magnets will be operated at rather low fields in the gap (0.02 T to 0.13 T) but up to the relatively high field of 1.5 T in the return yoke. Though the steel must have a low coercivity and high permeability, the most important requirement on the steel is a low spread of coercivity over the entire production.

Experience gained in the construction of similar magnets at CERN indicates that the required magnetic characteristics can be obtained by the use of low-carbon steel with a low content of impurities and by a combination of suitable annealing treatments and cold reductions. The magnetic characteristics indicated in this specification have actually been achieved in large scale industrial production for previous CERN projects.

1.2 Coercivity

The coercivity hereafter specified is the value of the magnetizing field which reduces the induction in the steel to zero from the value existing after complete saturation ($H_{max} \geqq 5000$ A m^{-1}).

The values of coercivity through the whole production must exhibit a very low spread with respect to a nominal value to be proposed by the steel maker after having produced the initial steel-sheet quantity of 1500 t. 95 % of the coercivity values must remain within a range of $\pm$ 8 A m^{-1} and the maximum deviation for each individual value may not exceed $\pm$ 11 A m^{-1} with respect to the nominal value. The nominal value must be as low as possible and in any case lower than 65 A m^{-1}. According to CERN's experience, the requirement for the low spread is more easily satisfied when the nominal coercivity is lower. For each eighth of the total delivery, the mean coercivity must stay within an interval of $\pm$0.5 A m^{-1} with respect to the nominal value.

1.3 Permeability

The required values of permeability, i.e. the ratios of magnetic induction to the applied field measured at points along the curve of first magnetization, and their permissible spread are usually specified, for the purpose of magnet design, as a function of the induction.

In order to facilitate measurements, the following equivalent specification of the induction as a function of the field is given:

a) At a field of 40 A m^{-1}, all measured values of induction must be higher than 0.04 T.

b) At a field of 1200 A m^{-1}, all measured values of induction must be higher than 1.5 T, and their spread, i.e. the difference between the highest and the lowest value, must be less than 0.06 T.

c) At a field of 24'000 A m^{-1}, all measured values of induction must be higher than 2 T.

Ageing

In principle, the steel supply should be entirely stable with respect to time in both coercivity and permeability. Since the operating temperature of the magnets is expected no to exceed 30°C, stability of the magnetic properties refers to several years of operation at this temperature.

As a practical criterion, it is proposed that the ageing properties of the steel sheets are evaluated by remeasuring the coercivity after 100 hours accelerated ageing at 150°C on samples from full-scale production. The values on the aged samples should not exceed those measured before accelerated ageing by more than 8 A m^{-1}. It is not proposed to perform systematic ageing tests throughout the production, but it is expected that the constancy of the ageing properties will be ensured by the constancy of the chemical composition and by the reproducibility of the production process. Therefore, the results of the chemical analysis carried out by the steel maker on each batch of steel and the records of the processing shall be made available to CERN. The relevant tolerances should be proposed by the steel maker and agreed by CERN.

Procedure for magnetic measurements

The magnetic characteristics should be controlled throughout the steel production by the following two distinct magnetic measurements:

a) A great number of coercivity measurements will be performed with a simple and rapid device, which will be located at the steel works and makes the results immediately available. For each delivery pallet

(Chapter 3), at least one sheet will have to be measured in its final condition. For those pallets which contain material from different coils, one sheet per coil will have to be measured. The total number of samples to be measured in this way for delivery pallets of about 1.6 tons may be of the order of 8000. Each pallet must be clearly labelled, in particular with its coercivity value and the number of its corresponding test file.

A preliminary description of the Coercimeter is given in Appendix 3.

b) A reduced number of complete measurements on the magnetic characteristics, i.e. coercivity and permeability, will be made with a semi-automatic permeameter which will also be located at the steel works. Samples will have to be taken from the beginning of every 10th steel coil in its final condition. The total number of samples to be measured may be of the order of 200.

The steel samples will have to be cut and prepared by the steel maker. A representative of CERN may be present during the preparation of the samples. For the coercivity measurements, no samples need to be cut, as entire sheets can be measured. For the complete measurements of the magnetic characteristics, each sample will consist of eight rings having an internal diameter of 76 mm and an external diameter of 114 mm.

The instrumentation for both magnetic measurements will be supplied by CERN. The measurements at the factory will have to be performed by the steel maker, but they will be supervised by a representative of CERN. The results of the measurements will be used for acceptance or rejection. In the event of an irresolvable dispute about the results of the measurements, a neutral institution will be requested to arbitrate.

1.6 Tolerances on magnetic characteristics measured on the samples

In principle, it is desirable that no steel sample should show magnetic characteristics outside the limits stated in Sections 1.2 and 1.3.

CERN reserves the right to refuse acceptance of a steel coil which exhibits unsatisfactory magnetic characteristics.

2. GEOMETRICAL AND MECHANICAL PROPERTIES OF THE STEEL SHEETS

Only some basic requirements are specified below. The detailed specifications and the acceptance procedures will have to be established by the contractor and must be agreed upon by the steel maker, the punching firm and CERN.

General

In order to maintain constant magnetic characteristics, no mechanical processing of the steel sheet, with the exception of punching, can be permitted after the sampling for magnetic measurements.

As a general requirement, the steel sheets in their final condition must be suitable for precision punching and for spaced assembly of the laminations in straight stacks.

Flatness and internal stresses

The sheets should be flat and free of internal stresses in order to avoid movements of the gap profile after punching and to permit regular spacing of the punched laminations during magnet fabrication.

Although the acceptance criteria and tests will be the responsibilty of the contractor, the following methods, which are based on CERN experience, are suggested:

a) When a sheet of dimensions 500 x 1020 mm^2 is laid on a marble, the distance from any point of the upper face to the marble must be smaller than 2.5 mm.

b) When a sheet is freely suspended, the sagitta in the rolling direction measured over a length of 1020 mm must be smaller than 10 mm.

Thickness

The average thickness of the steel sheets contained in each delivery pallet must be maintained within an interval of ±0.03 mm of the nominal value of 1.5 mm (as determined by weight).

The thickness of each individual steel sheet shall be kept within ±0.09 mm of the nominal value of 1.5 mm as measured at any point of the sheet.

The spread in thickness transverse to the rolling direction shall be kept within ±0.05 mm inside the region limited by two lateral strips of 10 mm width.

2.4 Surface quality

The surface of all sheets must be smooth. Flaws, cores and small pits, which should only be isolated ones, must not exceed the permissible thickness variation (see Section 2.3). The surface roughness shall be in the range 0.3 to 2 μm Ra (ISO/R468).

2.5 Inspection

It will be the responsibility of the punching firm to perform adequate geometrical and mechanical tests of the steel sheets during production and to define, in agreement with the steel maker, the precise methods of inspection. CERN must be informed of the methods of inspection agreed upon and the results must be made available to CERN.

3. FORM OF DELIVERY

The steel must be protected against corrosion by adequate greasing.

It is suggested that the steel sheets have the following dimensions:

- nominal thickness : 1.5 mm
- width : ~500 mm
- length : ~520 mm or ~1020 mm.

The sheets should be piled on standard pallets, properly packed and fixed, and protected according to standards for sea transport. The steel quantity per pallet must be chosen such as to correspond to a multiple of a batch of 174 punched laminations, but it shall not exceed the quantity corresponding to 3 x 174 laminations, i.e. approximately 1.6 t.

4. CONTROLLED STEEL MIXING

In order to obtain the required uniformity of the coercive force of the dipole magnets, the steel will have to be mixed. CERN intends to group batches of 174 ± 4 punched laminations according to coercivity. The coercivity spread within each group may be about 4 A m^{-1}. At the core factories, six batches will be selected for each dipole core in such a way as to reduce the coercivity spread of the finished cores to about 4 A m^{-1}.

As this process can only be applied to the available buffer at the core factories, which corresponds to about a one-month production, it is essential that the average coercivity of this buffer is close to the nominal coercivity. The steel maker is, therefore, requested to select the pallets for delivery to the punching firm according to their previously measured coercivities in such a way that the average coercivity for each two-week delivery period is within ± 2 A m^{-1} with respect to the initially defined nominal coercivity.

5. PRODUCTION RATES AND STORAGE OF STEEL SHEETS

According to the CERN planning, it is foreseen that the magnets will be produced at an average rate of 110 units per month, corresponding to an average steel delivery of 350 t per month.

To permit the determination of the mean coercivity, a large initial production of steel should be available and must be stored at the steel works. It is thought that this initial production should be of the order of 1500 t, i.e. one eighth of the total production. The subsequent production quantities must be sufficiently large, e.g. 500 t or more, to make an efficient mixing of the steel sheets possible, and must be stored at the steel works.

To ensure uninterrupted production of laminations, the steel quantity corresponding to a one-month production should be continuously stored at the punching works.